ARPA–E explores paths to emissions-free metal making

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MSc Pol Knops (Green Minerals)

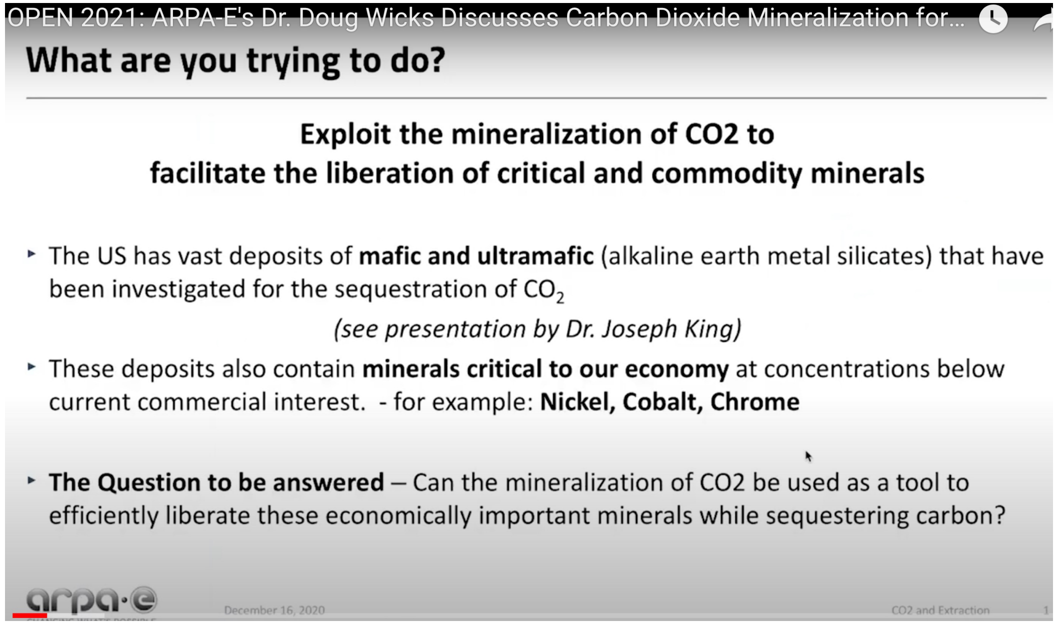
Quote from Wallace Broecker, Columbia University

(Broecker, *Elements* **3**, 295-298, Oct. 2008)

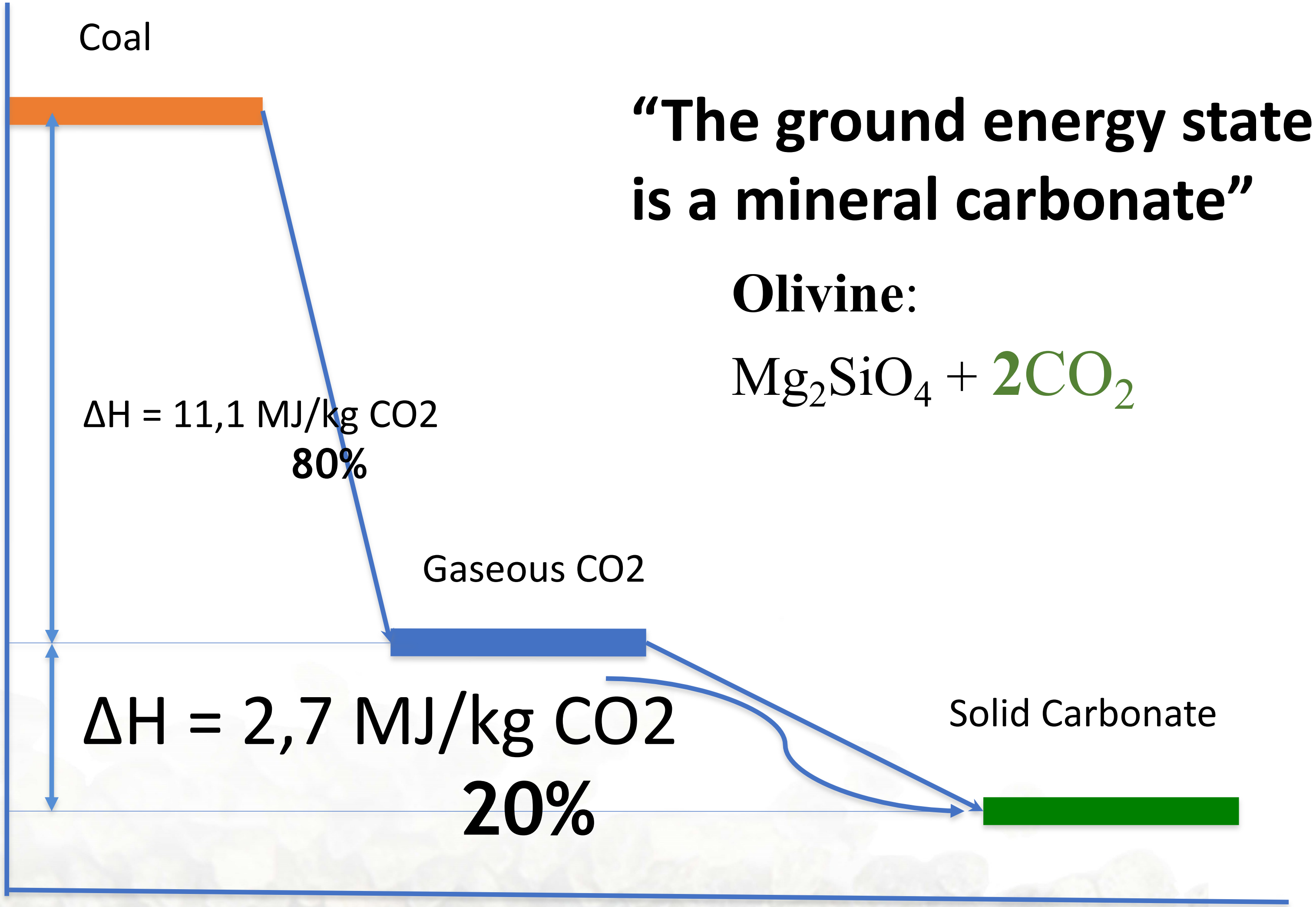
- "I am convinced that, in the long term, we must turn to solutions that involve chemical neutralization (immobilization) of CO_2, as opposed to simply storing it in gaseous form. Hence, I consider petroleum reservoirs and saline aquifers as interim storage solutions. Ultimately, we must learn to economically bind CO_2 with the magnesium and calcium contained in silicate rocks, whether it be under *in situ* or *ex situ* conditions."

Introduction

- Lecture of Doug Wick 16 December 2020
- Focus on **products, products**



Chemical formula



"The ground energy state of carbon is a mineral carbonate"

Olivine:

$Mg_2SiO_4 + \mathbf{2CO_2} \Rightarrow 2MgCO_3 + SiO_2$

[ΔH = **-239.2 kJ/mol**]

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Detail olivine composition

- Olivine: 93% Mg_2SiO_4

  7% Fe_2SiO_4

  0.3% Nickel

  0.3% Chromium

Products + markets

CO_2 sequestration	Service
Energy	- -
Magnesium-Carbonate	Filler
Amorphous Silica	Cement replacement
Iron	Ore substitute
Nickel	Ore substitute
Chromium	Ore substitute

Scaling up: step by step

Step 0: Research	1 kton CO2/yr
Step 1: Experiment, niche markets	5 kton CO2/yr
Step 2: Paper market	50 kton CO2/yr
Step 3: Concrete	500 kton CO2/yr
Step 4: Iron, Nickel, Chromium	5 Mton CO2/yr

General process

Mineralization reaction of Green Minerals:

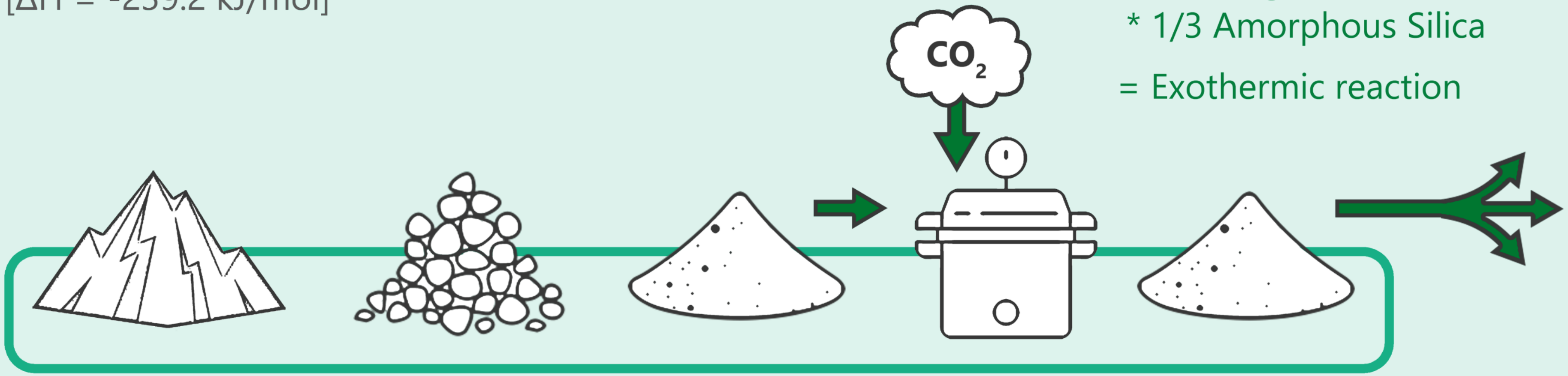
Mg_2SiO_4 (olivine) + $2CO_2$ => $2MgCO_3$ + SiO_2

[ΔH = -239.2 kJ/mol]

CO_2 additive contains very small particles

* 2/3 Magnesite
* 1/3 Amorphous Silica

= Exothermic reaction



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Step 2: Paper

		Flow	Price/ton	Revenue
.				
Throughput:	CO_2/yr	50 kton	100	27%
	Olivine/yr	100 kton	-40	
Products:	$MgCO_3$	90 kton	100	**49%**
	SiO_2	45 kton	100	**24%**
	Iron			
	Nickel			
	Chromium			
	Energy	4 MW(th)		

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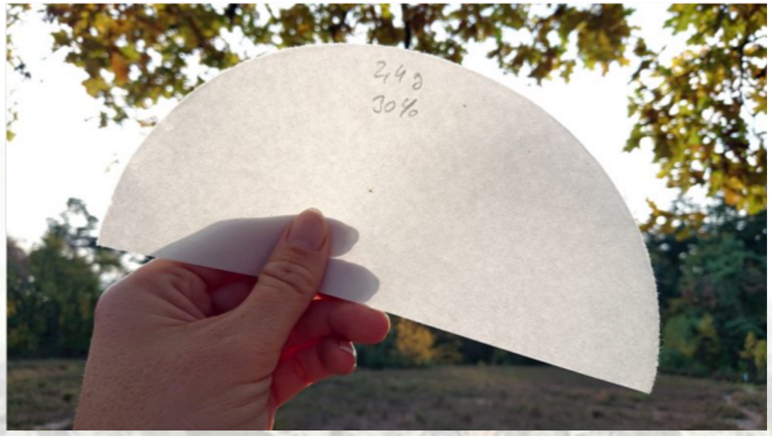
2. Paper tests

1st Tests:
CO2 Cleanup paper
University of Darmstadt
Prof. Schabel:
”The optical properties are better that I expected. The retention in the paper is quite good”

”But for a first ”shot” I would rate the results better as positive”



FACHGEBIET PAPIERFABRIKATION UND MECHANISCHE VERFAHRENSTECHNIK
Technische Universität Darmstadt
Alexanderstraße 8, 64283 Darmstadt
22.10.18

CO2_negatives_Papier

Coulter-Messung des gelieferten Carbonats					
Mittelwert: 54,4 µm					
Nur 10 % sind kleiner als 23 µm					
Gepresste Mineralientablette					
R457, %	Y-Wert	L-Wert	a-Wert	b-Wert	
53,2	58,9	81,3	-1,7	5,9	
Laborversuche mit Zellstoff					
	Laborblatt 80 g/m²				
Zugabemenge	Glührückstand	Reißlänge	Weiterreißarbeit	Berstfestigkeit	
%	%	km	mNm/m	kPa	
0	0,3	2,24	1.601	94,7	
15	14,9	1,78	1.242	79,7	
30	28,0	1,29	833	53,3	
40	41,1	0,89	609	30,7	
Bemerkung: Alle Laborblätter fühlen sich sandig an!					
Grund ist vermutlich die hohe Korngröße					
	Nutschenblatt, ca. 220 g/m² (C/2° UVEX)				
Zugabemenge	Glührückstand	Reißlänge	Weiterreißarbeit	Berstfestigkeit	
%	%	km	mNm/m	kPa	
0	0,2	2,24	1601	94,7	
15	13,2	1,78	1242	79,7	
30	26,8	1,29	833	53,3	
40	35,5	0,89	609	30,7	
	R457, %	Y-Wert	L-Wert	a-Wert	b-Wert
0	85,8	89,4	95,8	-1,00	2,80
15	81,8	86,2	94,4	-1,10	3,50
30	77,5	82,2	92,7	-1,20	3,90
40	75,1	79,8	91,6	-1,20	4,00

Particle size distr.

Brightness / Colour of mineral

Strength properties

Brightness / Colour of sheet

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Step 3: Concrete

		Flow	Price/ton	Revenue
.				
Throughput:	CO_2/yr	500 kton	+50	21%
	Olivine/yr	1 Mton	-40	
Products:	$MgCO_3$	900 kton	50	**39%**
	SiO_2	450 kton	**100**	**39%**
	Iron			
	Nickel			
	Chromium			
	Energy	45 MW(th)	-	-

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3. Concrete (Applications in concrete binder systems)

Confirmation of pozzolanic activity:

- it appears to be another <u>*SCM*</u> (*S*upplementary Cementitious Material)

  permitting replacement of clinker-based 'traditional cements'

  → CO_2 reductions ≈ 25% w/ combined with OPC

- it appears to be a *viable* <u>*'precursor'*</u> *(component for very-low carbon cements)*

  combined with alkaline activators: usage in 'geopolymers'

  → CO_2 reductions ≈ 60 - 85% w/ combined with OPC

Recommendations on particle properties

Improvement of size distribution and morphology: improved flow characteristics and mechanical performance

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sr. Materials Engineer - Cementitious Composites & MEO

SCS Sustainable Concrete Solutions

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Step 3: CO2 savings

- 1st replacment OPC
- 2nd CO2 used in production

Rock 'n' use of CO_2: carbon footprint of carbon capture and utilization by mineralization†

Hesam Ostovari,[a] André Sternberg ‡[a] and André Bardow *[ab]

A recent approach to reduce the carbon footprint of industries with process-inherent CO_2 emissions is CO_2 mineralization. Mineralization stores CO_2 by converting it into a thermodynamically stable solid. Beyond storing CO_2, the products of CO_2 mineralization can potentially substitute conventional products in several industries. Substituting conventional production increases both the economic and the environmental potential of carbon capture and utilization (CCU) by mineralization. The promising potential of CO_2 mineralization is, however, challenged by the high energy demand required to overcome the slow reaction kinetics. To provide a sound assessment of the climate impacts of CCU by mineralization, we determine the carbon footprint of CCU by mineralization based on life cycle assessment. For this purpose, we analyze 7 pathways proposed in literature: 5 direct and 2 indirect mineralization pathways, considering serpentine, olivine, and steel slag as feedstock. The mineralization products are employed to partially substitute cement in blended cement. Our results show that all considered CCU technologies for mineralization could reduce climate impacts over the entire life cycle based on the current state-of-the-art and today's energy mix. Reductions range from 0.44 to 1.17 ton CO_{2e} per ton CO_2 stored. To estimate an upper bound on the potential of CCU by mineralization, we consider an ideal-mineralization scenario that neglects all process inefficiencies and utilizes the entire product. For this ideal mineralization, mineralization of 1 ton CO_2 could even avoid up to 3.2 times more greenhouse gas emissions than only storing CO_2. For all mineralization pathways, the carbon footprint is mainly reduced due to the permanent storage of CO_2 and the credit for substituting conventional products. Thus, developing suitable products is critical to realize the potential benefits in practice. Then, carbon capture and utilization by mineralization could provide a promising route for climate change mitigation.

From Unavoidable CO_2 Source to CO_2 Sink? A Cement Industr Based on CO_2 Mineralization

Hesam Ostovari, Leonard Müller, Jan Skocek, and André Bardow*

Cite This: https://doi.org/10.1021/acs.est.0c07599 Read Online

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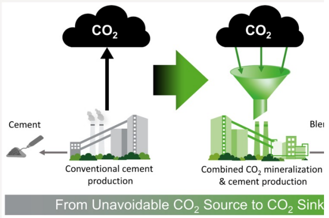
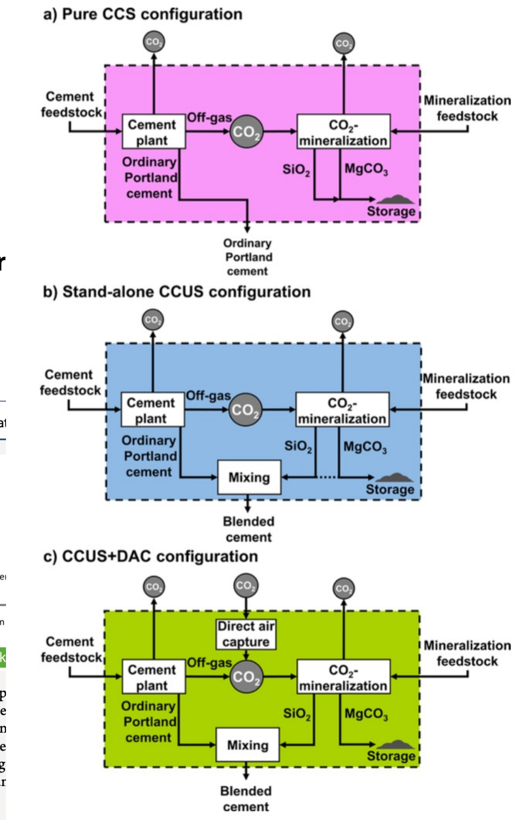
ABSTRACT: The cement industry emits 7% of the global anthropogenic greenhouse gas (GHG) emissions. Reducing the GHG emissions of the cement industry is challenging since cement production stoichiometrically generates CO_2 during calcination of limestone. In this work, we propose a pathway towards a carbon-neutral cement industry using CO_2 mineralization. CO_2 mineralization converts CO_2 into a thermodynamically stable solid and byproducts that can potentially substitute cement. Hence, CO_2 mineralization could reduce the carbon footprint of the cement industry via two mechanisms: (1) capturing and storing CO_2 from the flue gas of the cement plant, and (2) reducing clinker usage by substituting cement. However, CO_2 mineralization also generates GHG emissions due to the energy required for overcoming the slow reaction kinetics. We, therefore, analyze the carbon footprint of the combined CO_2 mineralization and cement p based on life cycle assessment. Our results show that combined CO_2 mineralization and cement production using today's e could reduce the carbon footprint of the cement industry by 44% or even up to 85% considering the theoretical poten carbon energy or higher blending of mineralization products in cement could enable production of carbon-neutral blende With direct air capture, the blended cement could even become carbon-negative. Thus, our results suggest that developing and products for combined CO_2 mineralization and cement production could transform the cement industry from an ur CO_2 source to a CO_2 sink.





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Step 4: Iron, Nickel, Chromium

			Price/ton	Revenue
.				
Throughput:	CO_2/yr	5 Mton	**+50**	50%
	Olivine/yr	10 Mton	-30	
Products:	$MgCO_3$	9 Mton	5	10%
	SiO_2	4.5 Mton	5	4%
	Iron	900 kton	50	8%
	Nickel	45 kton	2000	16%
	Chromium	45 kton	2000	16%
	Energy	450 MW(th)	- -	

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4 Metal extraction

- Confirmation separating Chromium
- Iron can be oxidized during operation
- First ideas Nickel recovery
- Nickel Sulphide ores becoming less common

Research questions

- Scaling up technology — Batch -> Continuous (HPAL, Bayer process)
- CO2 sourcing — BiCRS, DAC
- Economics = Market products — Paper ✅ / Concrete ✅ ☐
- Separation products — Metals ✅ ☐ ☐

Call to action

- How to proceed?
- Private / Government / Academic research project
- Preferred combined EU/US/CA project
- Combined funding

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